Refracting Telescopes

Nobody is sure of the date when the first telescope was made. It may be as far back as the early 1550s, when there is evidence that a telescope of some sort was constructed in England by Leonard Digges, but it is all very uncertain, and the first telescope of which we have definite proof was built by the Dutch spectacle maker H Lippershey in 1608. Others soon followed and were turned toward the skies. The first systematic telescopic series of observations was made in early 1610 by Galileo; others had preceded him, but for skill and perseverance Galileo stands alone in those very early days.

His telescope was, of course, a REFRACTOR. It was tiny, and even his most powerful telescopes magnified no more than 30 times, so that they were far inferior to modern binoculars, but they were the direct ancestors of the huge refracting telescopes of today.

In a refractor, the light from the target object is collected by a glass lens, known either as an object glass or as an objective. The light is passed down the telescope and brought to focus, where an image is formed and is enlarged by a second lens, termed an eyepiece or ocular. Note that it is the eyepiece which is responsible for the magnification; the function of the object glass is to collect the light—and, naturally, the greater the amount of light collected, the higher the magnification which can be used. The distance between the object glass and the focus is termed the focal length of the telescope. Magnification is given by the focal length of the telescope divided by the focal length of the eyepiece. The focal length of the telescope divided by the diameter of the object glass gives the focal ratio. Thus if a 3 in (7.6 cm) refractor has a focal length of 36 in (91.4 cm), its focal ratio is $36/3 = 12$ (in metric, $91.4/7.6 = 12$).

Assume now that with our 3 in refractor, with its focal length of 36 in, we use an eyepiece of focal length $\frac{1}{2}$ in. The magnification will be $36/\frac{1}{2} = 72$, often written as $\times 72$.

In theory, and usually in practice, eyepieces are made with a standard thread, so that any eyepiece can be used with any telescope. There is, however, one obvious limitation—the amount of light available depends on the aperture of the object glass (or the main mirror of REFLECTING TELESCOPES). Suppose, with our 3 in refractor, we use an aperture of $\frac{1}{8}$ in. The magnification will then be $36/\frac{1}{8} = 288$. Unfortunately, every time an image is enlarged it becomes fainter, and with this power on this telescope the image would be so faint that it would be completely useless. It is a general rule that the maximum really satisfactory magnification is $\times 50$ per inch of aperture, so that for our 3 in telescope the highest power which can be properly used is $3 \times 50 = 150$. For a higher magnification it is necessary to have a larger telescope. For example, a 6 in refractor of focal length 72 in will have a focal ratio of $f/12$. On this, an eyepiece of focal length $\frac{1}{4}$ in will give a magnification of $72/\frac{1}{4} = 288$, which is quite acceptable. If the focal length of our 6 in refractor is only 54 in, the focal ratio will be $54/6 = 9$. This makes for greater convenience, because the tube is shorter, but to make the f ratio too low will introduce other troubles, and one has to strike a happy mean.

With any telescope it is desirable to have several eyepieces: one to give low magnification and a wide field, suitable for observing objects such as star clusters; one with a moderate magnification, for views of the Moon and planets; one with high magnification, for use on really good, clear nights. With our 3 in, $f/12$ refractor, suitable eyepieces might well be of focal length 1 in ($36/1 = 36$), $\frac{1}{2}$ in ($36/\frac{1}{2} = 72$) and $\frac{1}{4}$ in ($36/\frac{1}{4} = 144$).

The main problem with a refractor is that it introduces what is known as chromatic aberration. Light is really a mixture of all the colors of the rainbow, and the color depends on the wavelength of the light; red light has the longest wavelength for visible radiations, violet the shortest, with orange, yellow, green and blue in between. When a beam of light is passed through a lens, it is split up, and the different colors are bent or refracted by different amounts—red least, violet most. They are therefore brought to focus at different distances from the object glass of a refractor, and an object such as a star is seen to be surrounded by gaudy colored rings which may look superficially attractive but which are most unwelcome to the astronomer.

The false-color trouble can be reduced by what is termed an achromatic object glass, in which there are several component lenses made of different kinds of glass; the errors then tend to cancel each other out. Some false color always remains, but with a good achromatic objective it is not really serious.

Bear in mind that an astronomical refractor will give an inverted image. In fact any refractor will do this, but in a telescope made for terrestrial use an extra lens system is put into the optical train to make the image erect. However, each time a ray of light passes through glass it is slightly weakened. This does not in the least matter when looking at birds, or ships out at sea, but it matters very much to an astronomer, who is anxious to collect every scrap of light available. Therefore, the erecting lens system is left out, although an erecting eyepiece can always be obtained.

The first known telescopes were refractors; the first REFLECTOR was not made until around 1669, when Isaac Newton believed that nothing could rid the refractor of severe chromatic aberration, and decided to develop an entirely different system (see NEWTONIAN TELESCOPES). Previously, efforts to eliminate false color meant that refractors were made with very long focal length. This does reduce chromatic aberration, but at the expense of making the telescopes very unwieldy. For example, Christiaan Huygens, probably the best observer of the early 17th century, constructed a telescope with an aperture of 2 in and a focal length of $10\frac{1}{2}$ feet and used it to discover Titan, the largest of the satellites of Saturn. He then built a telescope with a focal length of 23 feet, and with it discovered the true nature of Saturn's ring system. The telescope must have been incredibly awkward to use, and even more so were the refractors made and used by

Table 1. Some large refracting telescopes.

Name	Observatory	Aperture (in)	Date of completion
Yerkes 40 in	Yerkes, Williams Bay, WI, USA	40	1897
Lick 36 in	Lick, Mount Hamilton, CA, USA	36	1888
Meudon Refractor	Meudon, Paris, France	33	1889
Potsdam Refractor	Potsdam, Germany	31	1899
Lunette Bischoffsheim	Nice, France	30	1886
Thaw Refractor	Allegheny, Pittsburgh, PA, USA	30	1985
Grosser Refraktor	Archenhold, Treptow, Germany	27	1896
McCormick Refractor	Leander McCormick, Charlottesville, VA, USA	26	1880
26 in Equatorial	US Naval Observatory, Washington, DC, USA	26	1873
Thompson Refractor	Herstmonceux, England	26	1897
Innes Telescope	Johannesburg, South Africa	26	1926
Vienna Refractor	Vienna, Austria	26	1880
Newall Refractor	Athens, Greece	25	1862
Lowell Refractor	Lowell, Flagstaff, AZ, USA	24	1895

another pioneer observer, Hevelius of Danzig (the town now known as Gdańsk). One of Hevelius' telescopes had a focal length of no less than 150 feet, but was so subject to wind disturbance that it could seldom be used to its full potential.

Next came the 'tubeless' telescope. Here, the object glass was fixed to the top of a mast, and the observer sighted it by looking along guide wires which could be used to turn the object glass to the right position. The observer then held the eyepiece by hand. One of Huygens' 'aerial telescopes' had a focal length of 210 feet, and it is said that one refractor with a focal length of 600 feet was planned, although there is no record that it was actually built.

Obviously these long-focus telescopes could never be really satisfactory, but in 1733 a wealthy amateur astronomer, Chester Moor Hall, constructed the first achromatic or compound objective, with one component made of flint glass and the other of crown glass. The idea was taken up by John Dollond, and this led on to what was probably the first 'optical firm' in history. In 1765 John's son, Peter Dollond, took one of his achromatic objectives to the Royal Observatory at Greenwich, and its performance was found to be far better than that of the Observatory's best long-focus telescope. The old aerial refractors promptly became obsolete. Moreover, Dollond's telescopes looked attractive. From about 1783 they were made with brass tubes; when set up on well-made mahogany stands they were easy to use and were fitted with slow motions.

By the first part of the 19th century it had become possible to make really good objectives. Then, in 1862, Thomas Cooke, in England, built the first of the 'great refractors'; it is known as the Newall Telescope and had an objective of 25 in across (it is still in use, at the Athens Observatory in Greece). Between 1870 and 1900 even larger refractors were built, culminating in 1897 with the 40 in telescope which was set up at the Yerkes Observatory in Wisconsin, USA. At the time, and for some years afterwards, it was the most powerful telescope in the world, and it proved to be a great success. It is still in use on every clear night.

Could it be possible to build a refractor of greater size than the Yerkes 40 in? Theoretically, yes, but there were serious practical difficulties. If a lens is too large it will begin to distort under its own weight, and this will make it useless. An attempt was made at the very end of the century, when a 49 in objective was made in France. The 180 foot tube could not be mounted in the conventional way; instead it was left horizontal, and the light was brought to it by means of movable mirrors. The telescope was shown at the Paris Exposition of 1901, but it was clearly a failure, and it was never used for any astronomical work. Before long it was dismantled, and the fate of the object glass is unknown. The fate of a 41 in, destined for the Pulkovo Observatory in Russia, was even worse; before the optics could be completed, the mounting of the telescope had rusted away.

By then it had become possible to build very powerful reflecting telescopes, and these were not subject to size limitation, because a mirror can be supported by its back; light does not have to pass through it. A few large refractors have been made in the 20th century, but not many are used by professional astronomers except for very specialized programs, and it is undeniable that the future of the telescope lies with the reflector.

Yet in amateur hands, the refractor remains ideal. It is much less delicate than a reflector and will need little maintenance; if it is treated with care, it will last a lifetime and more. Although its color correction can never be as good as that of a reflector, it will give superb, clear-cut images.

Choosing a refractor for home use is something to be undertaken with care, because a poor-quality telescope does not betray itself at a glance. Some small refractors are sold according to the power available—or so it is claimed; it one recent advertisement it was said that the telescope offered 'would magnify 750 times'. The aperture of the object glass was however only 3 in, so that the maximum power which could be used to advantage was no more than

150. Aperture is all-important, and a telescope advertised without giving the diameter of the objective should be avoided. Watch too for a ring fixed inside the top of the tube, masking the outer part of the objective and thereby cutting down the aperture; this is a trick designed to conceal defective optics.

Generally, it is not really sensible to spend much money on a refractor with an object glass less than 3 in in diameter. Of course a smaller instrument, such as a 2 in, is better than nothing at all, but given a choice between a very small telescope and a pair of good binoculars it is certainly better to opt for the binoculars.

A refractor of aperture up to 4 in is easily portable, although a larger instrument will be too heavy to move around, and will be best set up in a permanent observatory.

Some large refracting telescopes are listed in table 1.

Patrick Moore